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Position sensitivity in large spectroscopic LaBr3:Ce crystals for Doppler broadening correction

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ABSTRACT

The position sensitivity of a large $LaBr_3$:Ce crystal was investigated with the aim of correcting for the Doppler broadening in nuclear physics experiments. The crystal was cylindrical, 3 in × 3 in (7.62 cm x 7.62 cm) and with diffusive surfaces as typically used in nuclear physics basic research to measure medium or high energy gamma rays (0.5 MeV < E_γ < 20 MeV). The crystal was coupled to Position Sensitive Photomultipliers (PSPMT). The signals from the 256 segments of the four PSPMTs were acquired grouping them into 16 elements. An event by event analysis was performed and a positon resolution of the order of 2 cm was found. It was verified that this allows an important reduction of the Doppler broadening induced by relativistic beams in Nuclear Physics experiments.

1. Introduction

The properties of $LaBr_3$:Ce material are well known: it is an inorganic scintillator characterised by high yield, high density, excellent energy and time resolution [1]. Several groups have been investigating the position sensitivity properties of this material, mostly in medical field (see for example Ref. [2–7]). In this field, the goal is to locate the position of a well known gamma-emitter with a precision as good as possible. Usually, the detected gamma rays are the 140 keV from ^{99m}Tc or the 511 keV from the positron annihilation process. It was found that in gamma-cameras for small animal SPECT a sub-millimetre position resolution can be obtained due to the high light yield of $LaBr_3$:Ce (see for example Ref. [8–11]). Because of the high position resolution required, the crystals used in this field are rather thin, their thickness being of the order of 1 cm or less. Furthermore, they are provided with absorbing surfaces, so to avoid the reflected scintillation light to reach the photocathode and spoil the position sensitivity. However, this affects the energy resolution.

On the other hand, in nuclear physics basic research, $LaBr_3$:Ce crystals are employed to study the decay properties of nuclei populated via nuclear reactions. In this case, the position of the emitter is well known, while the energies of the gamma transitions are not known and may range up to several MeV. Therefore, detectors with good energy resolution and high efficiency are needed. These two requirements are fulfilled by diffusive surfaces in order to collect all the scintillation light, and large thicknesses (> 3 cm). Lately, the availability of exotic beams made possible to study nuclei far from stability via reactions where the nucleus under study is moving, it excites interacting with a target nucleus at rest and de-excites by radiation emission while it is still moving. These exotic beams can reach velocities up to v/c of the order of 0.7 or more [12,13]. In the lab system, the energy of a gamma ray emitted by a moving source depends on the emission angle due to the Doppler effect. Therefore, since the detector covers a non negligible solid angle, the detected energy resolution is deteriorated. To give an example, for a 3"x3" $LaBr_3$:Ce detector placed at 20 cm distance from the target, the resolution of 1 MeV gamma ray is 25 keV when the emitter is at rest, 70 keV when it moves with v/c=0.3 or 150 keV for v/c=0.7. The problem of Doppler broadening is quite serious in nuclear physics. In fact, it was one of the main reasons for the development of specific arrays made of segmented HPGe crystals [14,15]. With these arrays it is possible to track the gamma ray, to identify its first point of interaction, calculate the emission angle and convert its energy to the centre of mass value [16]. The energy resolution of these arrays is excellent, which is very advantageous in spectroscopy studies below particle threshold, but the system is complex, expensive, hardly transportable from one lab to the other, and the required data analysis is quite sophisticated.

On the other hand, an excellent energy resolution is only needed in spectroscopy studies of high density transitions spectra. In the two opposite cases of low density transition spectra or giant resonances at high excitation energies, 4 or 5% energy resolution

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Table 2
Energy recalibration of the ^{88}Y data, assuming a moving source with v/c=0.5, and the detector placed at 20 cm and at 90° with respect to the source velocity direction. The first column indicates the centre position of the window source in the x direction relative to the crystal surface centre, the second column indicates the calculated lab angle, in the third and fourth columns the calculated "lab energies" of the ^{88}Y source transitions 898 keV and 1836 keV used for the calibration.

X (cm)	θ (°)	898 (keV)	1836 (keV)
2.5	97.1	732.3	1497.2
1.5	94.3	749.7	1532.7
0.5	91.4	768.1	1570.4
−0.5	88.6	787.5	1610.1
−1.5	85.7	807.9	1651.8
−2.5	82.9	829.1	1695.2

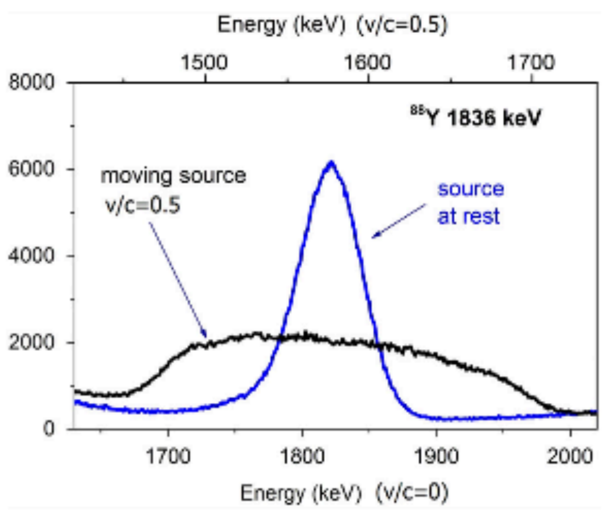

Fig. 10. The black line shows the spectrum of the 1836 keV simulating a source moving with v/c=0.5, as explained in the text. The energy scale is on the top of the figure. For comparison, the original spectrum is also shown (blue line, energy scale on the bottom of the figure). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

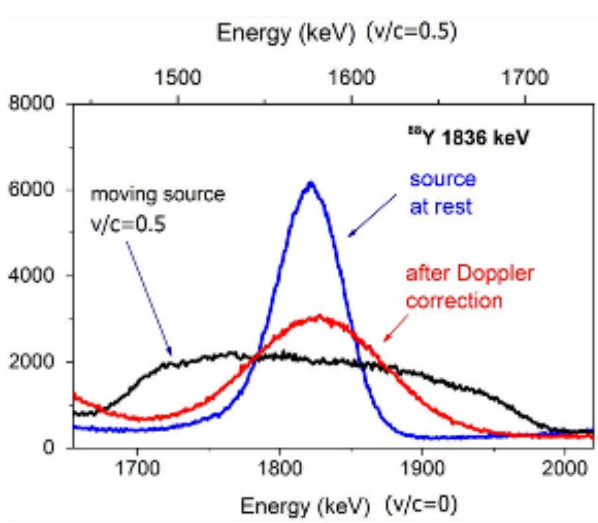

Fig. 11. The spectrum obtained after Doppler correction (red line) is compared to the spectrum simulating a source moving with v/c=0.5 (black line) and to the original spectrum (blu line). For details see the text. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

reported. In the lab system, the energy corresponding to the 1836 keV transition would range from ~1500 keV for angles smaller than 90° to ~1700 keV for larger angles. Recalibrating each set of data and summing up the data, a spectrum was obtained which simulates the effect of Doppler broadening in an inverse reaction experiment. Fig. 10 shows the resulting 1836 keV peak (black line, energy scale on the top) compared with the original peak (blu line, energy scale on the bottom). The effect of the moving source simulation is to spread the 1836 keV peak over ~ 250 keV.

The successive step was to correct the "Doppler broadened" data via an event by event analysis, calculating the incidence angle from the measured position and transforming the "lab energy" into "c.m. energy". In the resulting spectrum, shown in Fig. 11 (red line), the 1836 keV peak has a FWHM of ~100 keV, with an improvement factor of ~2.5.

4. Conclusions

We investigated the position sensitivity of a spectroscopic 3 in × 3 in LaBr3: Ce detector using an intense ^{137}Cs collimated beam of 1 mm diameter (662 keV gamma ray) and a ^{88}Y source (1832 keV) collimated with 20 cm Pb leaving a 1 cm wide and 5 cm high window. The event-by-event analysis was performed using four Position Sensitive Hamamatsu H8500 PMT's, with segments short-circuited in groups of 16, so to have only four "macrosegments" for each PMT. The crystal surface was then covered by 12 such "macrosegments". By measuring the collimated sources in several positions, we found a position sensitivity with a resolution of the order of 2.3 cm for 662 keV and 2 cm for 1832 KeV gamma rays. In order to investigate whether this resolution would be sufficient to correct for Doppler broadening in nuclear physics experiments with exotic beams, we simulated experimentally the case of a 1836 keV gamma ray (^{88}Y source) emitted by a moving source with v/c=0.5 at 20 cm distance. The energy resolution, which is 50 keV for the source at rest, would then be ~250 keV for the moving source. By reconstructing the gamma interaction point we could correct for the broadening by a factor 2.5 and obtain a resolution of 100 keV. This demonstrates that the position sensitivity of large LaBr3: Ce might be used in nuclear physics experiments for studies where an energy resolution of 4–5% at 1 MeV is needed, and a correction of the Doppler broadening might be obtained with a relative simple setup and data analysis.

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